Practical Experiences from Four HLA Evolved Federations

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ABSTRACT: *HLA Evolved was formally published in 2010 but early federations based on this standard have been developed since 2008. This paper summarizes experiences from four federations during the period 2009 - 2011 with focus on maturity and on the use of new HLA Evolved features. The federations are as follows:*

Viking 11 is the world's premier joint civil-military-police exercise involving more than 2500 persons from 31 nations distributed across nine sites. The purpose is to acquire hands-on practical skills and knowledge of civil-military-police coordination and cooperation before deployment in multifunctional and multinational UN mandated peace operation. The exercise was successfully carried out in April 2011 using an HLA Evolved infrastructure with participants running federates in different countries, proving the maturity of HLA Evolved.

NATO MSG-068 had the purpose to create a reference federation architecture for the NATO Education and Training Network with participants from, the US, UK, France, Germany, the Netherlands, Spain, Australia, Bulgaria, Romania, Turkey and Sweden. Participating systems include JCATS, JTLS, ICC, VBS2, WAGRAM, ORQUE, KORA and more. The HLA Evolved infrastructure proved to be stable during the experiment. HLA Evolved FOM Modules were used to mix standardized FOM data, like RPR with NATO extensions.

SISO Smackdown is a university outreach program, with participation from NASA and universities worldwide. Based on a lunar mission scenario it allows universities to extend the common information model to fit their part of the scenario. This extensibility is based on the HLA Evolved modular FOMs. Since this project uses RTIs from two different vendors it also illustrates how federations can benefit from the HLA Evolved Dynamic Link Compatible APIs.

BAE Systems Command and Control Demo Federation. This is a proof of concept for fault tolerance and load balancing. It uses fail-over federates based on the new HLA Evolved functionality. Another feature is the use of HLA Evolved Smart Update Rate Reduction for dynamic control of tactical data update rates on mobile devices.

The conclusion is that HLA Evolved is mature and that most of the new features have already been successfully used.

1. Introduction

This paper focuses on how the new version of HLA, formally called IEEE 1516-2010 and informally known as HLA Evolved [1], has been used in real life. It gives some background on why standards need to be maintained over time. It summarizes the new technical features of HLA Evolved. It then looks at how HLA Evolved and the new features have been used in some federations and provides some discussions on this

1.1 Evolving standards

Technical standards need to be maintained for several reasons.

- Solutions building on standards have evolving requirements. As an effect of this, the requirements on a standard and the features that it provides also needs to evolve.
- As technology in general develops, there are also new ways to implement technical features and new types of functionality that can be provided. Standards need to take advantage of this to improve or they will be replaced by newer standards.
- As different people implement a standard they may interpret it differently. This contradicts the purpose of standards, so this needs to be resolved.

- There will always be typos and inconsistencies in a standard that need to be corrected.

HLA was developed as a successor to DIS [2] and ALSP to provide one common architecture for simulation interoperability within the US Department of Defense. After a number of prototype federations the first complete version, HLA 1.3 [3] was released in 1996-1998 as a US DoD standard.

HLA was then taken to IEEE to become an open international standard. It was foreseen that there would be considerable synergies with sharing a standard for simulation interoperability with the civilian market. An international standard would also be advantageous when interoperating with coalitions partners outside of the US. The result was an HLA version called IEEE 1516-2000 [4].

All IEEE standards need to be opened for review regularly. They can then be revised, reconfirmed as is or retired. When the HLA standard was opened for review it had been used extensively in many projects. This feedback resulted in a large number or updates. The next (and current) HLA versions was developed by SISO and released by IEEE in August 2010 and it was formally named IEEE 1516-2010.

The version numbering of HLA (1.3, 1516-2000, 1516-2010) is somewhat confusing. If HLA were to be released as a commercial software product it can be argued that HLA 1516-2000 would have been called HLA 1.4 (minor upgrade) and HLA 1516-2010 would have been called HLA 2.0 (major upgrade).

1.2 Main technical improvements from HLA 1.3 to HLA 1516-2000

HLA 1516-2000 adds the following new features when compared to HLA 1.3:

- The Data Distribution Management (DDM) services where redesigned for greater flexibility. In HLA 1.3 dimensions were grouped into predefined routing spaces. Starting from HLA 1516-2000 a set of dimensions can be defined for an attribute or an interaction. These can then be freely combined at runtime as part of subscriptions or updates or interactions.
- The OMT format, used to specify FOMs and SOMs used, at that time, new XML Format, including a DTD definition.
- One update not to be underestimated was the introduction of fully specified data types in the OMT. One major cost driver during federation integration is unclear or misunderstood data representation when exchanging information.

Numerous other changes and clarifications were also made. One particular interesting one was a change in the semantics of publish and subscribe, making them additive instead of replacing, which in practice affected very few federates.

1.3 Main improvements from HLA 1516-2000 to 2010

A large number of updates were made to the HLA standard in the 1516-2010 version, both editorial and technical. Another paper [5] summarizes the technical updates in detail. This paper focuses on larger technical updates. These include:

- Modular FOMs [6] that enables a FOM to be built from modules. A module can contain objects, interactions and data types that relates to a well-defined sub-problem, like radio communications or federation management. This enables not only development and maintenance on a module level but also reuse and standardization in a modular and composable fashion.
- XML Schemas [7] for compliance testing of a FOM or a SOM replaced the previous DTD. A majority of the OMT specification requirements are covered by these XML Schemas. Some standards requirements cannot be checked by an XML Schema, for example multiple subclasses with the same name in the object or interaction class hierarchy.
- Fault Tolerance [8] support that includes a well-defined semantics for the RTI to signal to a federate if it has lost connection to the federation or if another federate has been lost.
- Web Services API [9] that enables a federate to call the RTI using Web Services instead of the C++ or Java API.
- Smart Update Rate Reduction [10] (SURR) that enables a federate to subscribe to updates with a particular upper threshold on the update rate.
- Improved Data Logging support that enables a federate to determine which federate that sent a certain update or interaction
- Standardized Time Representations [11] which provides two standard ways to represent time stamps independent of which RTI implementation that is used. One representation is an integer and the other is a float.

- Evolved Dynamic Link Compatibility (EDLC) for the C++ and Java APIs or the RTI. This enables a federate to use different RTIs without recompilation.

1.4 Sample federations

We will now look at a number of sample federations using HLA Evolved. Four major federations that use HLA Evolved and that are known to the authors have been selected. A few additional cases have been added to provide more examples. Today there are RTI implementations for HLA Evolved from at least three major RTI vendors (MÄK, Pitch and Raytheon-VTC) so nobody knows the total number of HLA Evolved RTI licenses in use and the number of HLA Evolved federations that are completed or under development.

2. Viking 11

2.1 Purpose

Viking [12] is the name of a series of combined civil-military crisis response operations exercises that have been carried out since 1999 under a joint Swedish and US initiative. The 2011 exercise focused on planning and conducting a United Nations mandated Chapter VIII peace operation/crisis response operation. The training event had about 2500 persons from 31 nations involved. The event involved not only national defense forces and blue-light organizations but also 35 non-governmental organizations (NGOs).

One of the more important requirements was to use a comprehensive approach, which is when military; police and civilian personnel operate together towards a common goal. The main focus was on CIMIC (Civilian-Military Cooperation) and command and control training. This includes using real operational command and control systems wherever possible. Computer based simulation systems were used to simulate the environment and scenario in order to stimulate the training audience.

The exercise builds upon a scenario called Bogaland [13], which has been developed in Sweden over a long time specifically for this type of exercise. It involves several fictional areas (East & West Kasuria, East & West Mida and Gotland) with several ethnic groups, uneven distribution of wealth, areas rich in natural resources like oil and gas and other areas with illegal economic systems. There are different ethnic and religious groups and the different governments are not in full control of their respective countries. There are a wide variety of issues to deal with, including protection of civilians, fighting piracy and hostile elements, dealing with irregular forces, reconstruction work and new developments as well as handling children taking part in armed conflicts.

The exercise ran for two weeks in April 2011 with a large number of training systems interoperating using an HLA Evolved infrastructure. The federation was stable for the duration of the exercise although a few of the participating systems had temporary issues. The official conclusion from

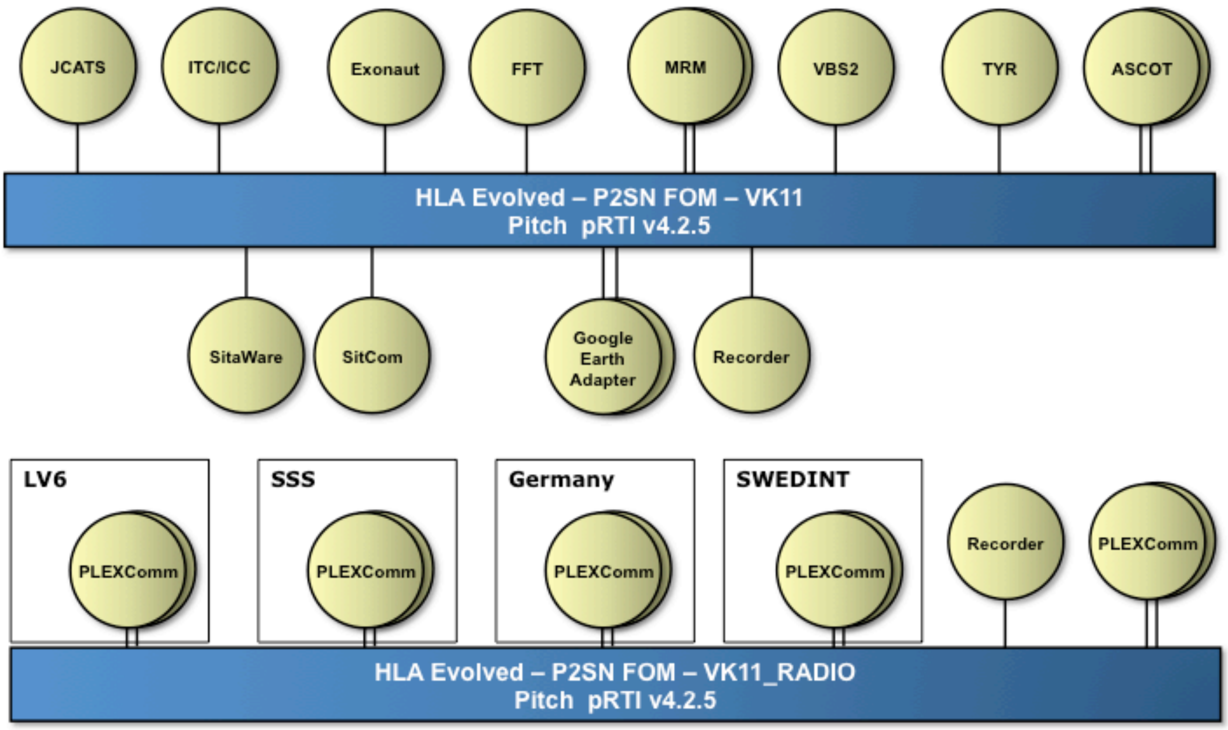

Figure 1: Viking 11 main federation and radio federation

the exercise was that *"It has been a great success and many innovations have been a first"*. This exercise was also mentioned in the ITEC 2011 keynote as *"the world's premier civil/military exercise"*.

2.2 Federation

The federation included systems both for the training audience and for the exercise control. The training audience was supported by systems providing a common operational picture, recognized air, land and maritime pictures, a tactical unmanned aerial vehicle view, civil/police situation awareness views, communication, collaborative tools, map tools and more. Systems for exercise control provided overall exercise management, *"God's Eye"* views, situational awareness, communication, collaboration tools and more.

A number of training systems were used including operational C2 systems, standard training systems and tailored systems. Some of the systems used include:

- JCATS, a well-known simulator, sponsored by US JFCOM and developed by LLNL, used for aggregated and platforms, regularly used for example by the US Marines.
- ICC, the operational NATO C3 system for showing and handling a recognized air picture for military air traffic controllers.
- ITC, a platform-level simulator owned by NATO, based on the Ternion Flames framework, that generates the air picture for ICC.
- Exonaut, a COTS, web-based, exercise management and planning tool used in the MEL/MIL approach, developed by 4C Strategies.
- FFT, the Friendly Force Tracker, a tailored application developed by Pitch, reports ground truth data from specific platforms or aggregates to C2 systems.
- MRM, the Multi Resolution Model, a tailored application developed by BAE Systems C-ITS, de-aggregates an aggregate unit into platforms.
- VBS2, a COTS game-based training system on the platform level by Bohemia Interactive, used to visualize the current situation from UAV and helicopter views.
- TYR, the major Swedish aggregate level war-gaming system from BAE Systems C-ITS.
- ASCOT, a training system for military air traffic controllers. This is a COTS application by PLEXSYS.
- SITAWARE HQ and WEBCOP, an operational C2 system is a COTS product from Systematic. It is regularly used by the armed forces of Sweden, Denmark, Finland, Germany and several other countries.
- SitCom, a tailored application developed by BAE Systems C-ITS, reports perceived truth from aggregated units in TYR to the federation.
- Google Earth PRO, connected to the federation through the COTS product Pitch GE Adapter. It was used for reporting situation awareness for blue-light and civilian participants that in many cases do not have their own C2 systems.
- PLEXComm, a radio communication simulator used to handle radio traffic exchange during the exercise. This is a COTS application by PLEXSYS.
- A FOM-agnostic data logger, Pitch Recorder, was used for collecting all Federation data exchange from the different Federations of the exercise.
- A COTS product for bridging and data filtering federate, Pitch Extender, was used to limit data exchange and to connect multiple federations.

The training systems were distributed across nine sites and the scenario included between 100 000 and 1000 000 entities. Many of these entities were dynamically aggregated and de-aggregated when needed, resulting in only 10 000 to 15 000 entities being registered in the federation at any single moment.

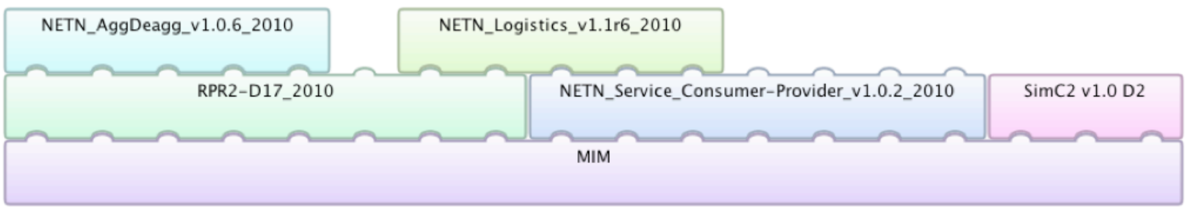

Figure 2: Viking 11 FOM modules

2.3 HLA Evolved aspects and experiences

The most important observation made here is that it is possible to carry out possibly the world largest comprehensive exercise with thousands of participants in different locations using HLA Evolved. The scenario was large, many operational systems from several providers were used, and the exercise ran for two weeks. This proves that HLA Evolved and many implementations (RTIs, tools, federates) have reached maturity for widespread deployment. The RTI used, Pitch pRTI Evolved was further optimized and tailored for large federations and severely memory-constrained federates during the early integration tests.

The federation used HLA Evolved Modular FOMs. The FOM Modules used were mainly the same as in the MSG-068 project described below, plus an additional module, SimC2 ("simulator to C2"). This set of FOM Modules is also known as the P2SN FOM version 2 where P2SN stands for Persistent Partnership Simulation Network, a cooperation between US JCW and the Swedish Armed Forces.

The federation had a mix of federates using the older HLA 1.3 and HLA 1516 APIs, as well as some using the new HLA Evolved APIs. While this is sub-optimal in the long run it makes it possible to quickly start reusing older systems in an HLA Evolved context.

Some of the tailored federates, namely the FFT, the MRM and the SitCom, were developed using a middleware generator, Pitch Developer Studio [14], which given a FOM generates middleware that supports both HLA Evolved and older HLA versions without recompilation.

3. NATO MSG-068

3.1 Purpose

The mission of the NATO Modeling and Simulation Group (MSG) is to promote co-operation among Alliance bodies, NATO member nations and partner nations to maximize the effective utilization of M&S. NMSG is part of the NATO Research and Technology Office (RTO). The group NMSG-068 focused on developing recommendations for a NATO Education and Training Network, NETN. Such a network should *"integrate and enhance existing national capabilities and focus on the education and training of NATO Headquarters' staffs and NATO forces. A NETN consisting of a persistent infrastructure, distributed training and education tools, and standard operating procedures not only supports the training of NATO headquarters but also enables the Nations to collaborate with each other".*

MSG-068 [15] had more than 140 experts collaborating, representing Joint Warfare Center, Joint Force Training Center, NC3A, ACT, US JFCOM, Australia, Bulgaria, France, Germany, Hungary, The Netherlands, Romania, Spain, Slovenia, Sweden, Turkey and the UK.

The project developed a federation agreement and a set of FOM modules for a NETN. A number of design patterns were developed, for example how entities in one simulator can requests services, for example logistics, from another simulator. Another pattern was the modeling of transfer of control for resources and entities between different simulations.

More than eight major integration and test events took place with different combinations of systems and focusing on different tasks such as convoy, repair, supply patterns and more. This lead up to a main experiment in October 2010 involving multiple training centers and national battle-labs and a demonstration at I/ITSEC 2010.

The work of MSG-068 continues in MSG-106 with additional focus on operational requirements and support to CAX. A lot of new developments in M&S in NATO build upon the MSG-068 work;

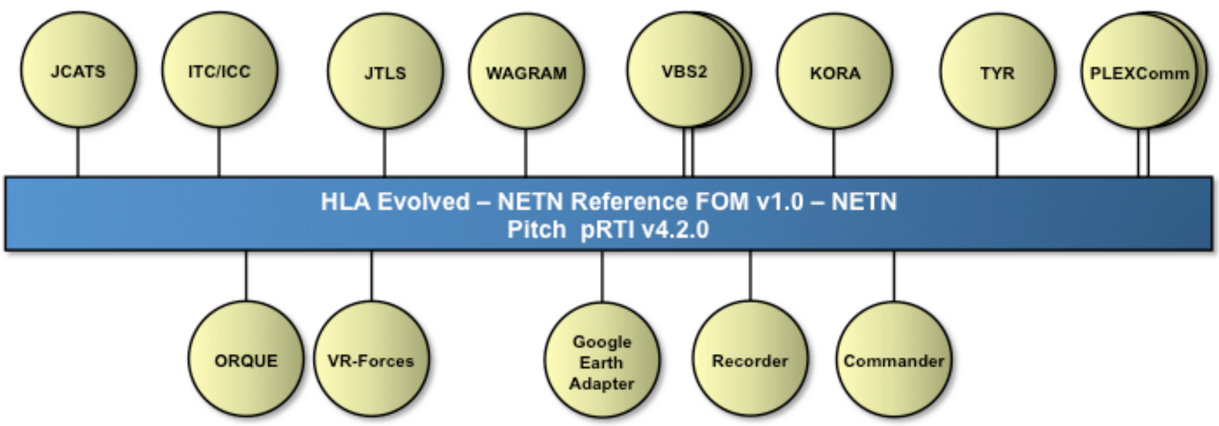

Figure 3: NATO MSG-068 federation

Viking 11 (above) is one example of this.

3.2 Federation

A number of experimental federations were developed and executed as part of the project. Examples of participating NATO and national systems and tools are: JTLS, JCATS, JPECT (ITC-FLAMES/ICC), VBS2 through LVC Game, FACSIM, MäK VR-Forces, MäK Stealth Viewer, WAGRAM, ORQUE, ALLIGATOR, PLEXComm, KORA, PsiWeb, Marcus, CATS TYR, Netscene, Google Earth PRO, Pitch GE Adapter, Pitch Commander, Pitch pRTI Evolved, Pitch Booster and Pitch Recorder.

3.3 HLA Evolved aspects and experiences

This project started using early versions of HLA Evolved. It was one of the first to work with modular FOMs in practice. There were minor fixes to the HLA Evolved APIs during this project but no major changes in the functionality. By the end of this project there were not only a stable RTI for HLA Evolved available but also a number of general purpose HLA Evolved tools.

This project pioneered the work with full-scale FOM module development. The set of FOM modules developed consists of a base with the RPR-2 FOM draft 17 [16]. It adds a service consumer/provider module and on top of this a Logistics module. A Link-16 [17] module (described as a "BOM") is included. A special Federation Execution Management module was also developed. A special module for aggregation and de-aggregation was also developed.

The federation also had a mix of federates using the older HLA 1.3 and HLA 1516 APIs as well as the new HLA Evolved APIs.

MSG-068 also contribute to the continued work with standardizing RPR-FOM v2.0 by providing a proposed set of HLA FOM modules that represents the full RPR-FOM v2.0 D17 object model to the SISO RPR-FOM PDG.

4. SISO Simulation Smackdown

4.1 Purpose

SISO Simulation Smackdown [18] is an outreach program where university students are invited to participate in building HLA federations together with NASA, one of the sponsors of the project. The purpose is to promote modeling and simulation subjects in education. NASA provides some basic federates and HLA vendors (ForwardSim, MÄK and Pitch) provide HLA tools and RTIs. Aegis provides coordination and mentoring. SISO host locations and provides coordination and funding. Participating universities at the 2011 Smackdown came from North America, Europe and Asia.

4.2 Federation

The scenario is space mission support in the proximity of the Earths moon. Participating federates include:

- An environmental federate with the position for the Sun, Earth and Moon as well as a federate with a simple transfer vehicle, provided by NASA

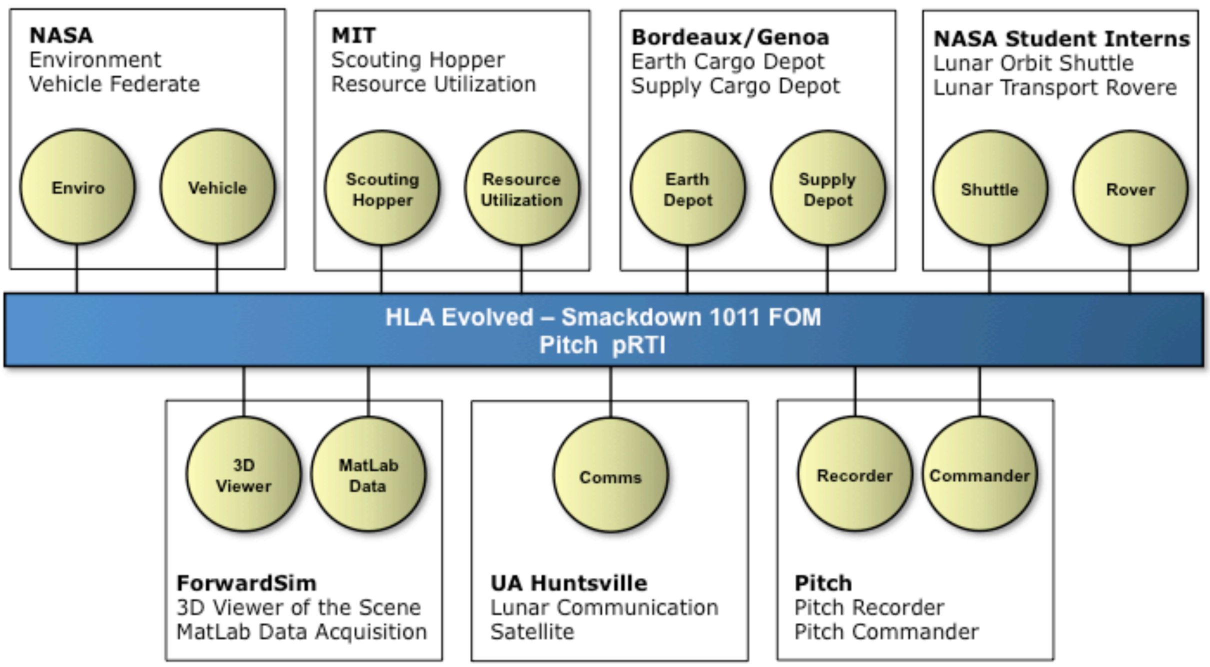

Figure 4: SISO Smackdown federation

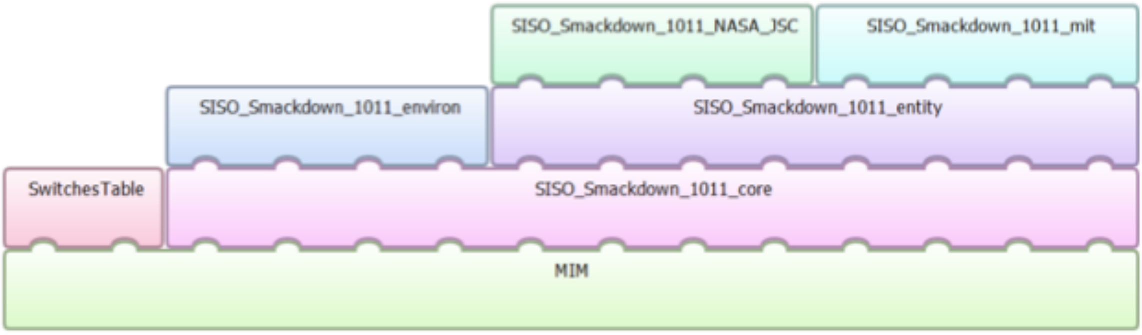

Figure 5: SISO Smackdown FOM modules

- Earth cargo depot and supply cargo depot federates from the University of Bordeaux/Genoa team.
- Lunar communication satellite federate from the University of Alabama Huntsville team.
- A high-mobility scouting hopper and a mobile in-situ resource utilization plant federate from the MIT team
- A lunar orbit shuttle and a lunar transport rover federate from the NASA student intern team
- A 3D viewer of the scene from ForwardSim
- Federates from Keio University of Japan, which unfortunately had to withdraw due to the events in Japan.
- Data loggers from MÄK and Pitch

This federation used HLA time management.

4.3 HLA Evolved aspects and experiences

This federation used several HLA Evolved features. First of all the modular FOM approach was used with three common FOMs: the Core FOM, the Environment FOM and the Entity FOM. Students teams that needed additional concepts added more FOM modules.

Since this federation used both the MÄK and the Pitch RTI the Evolved Dynamic Link Compatible (EDLC) APIs were tested in practice. Some federation executions were done using the MÄK RTI and some using the Pitch RTI.

The federation also used an HLA Evolved standardized time representation.

5. BAE Systems C2 Demo

5.1 Purpose

A group within BAE Systems has developed a fault-tolerant, low-bandwidth training concept. It has been demonstrated for a number of customers. It contains several solutions for common problems in C2 training exercises on the tactical/platform level. It uses a number of interesting features based on HLA Evolved. One of them is fault tolerance. Another one is the ability to do load balancing between simulations.

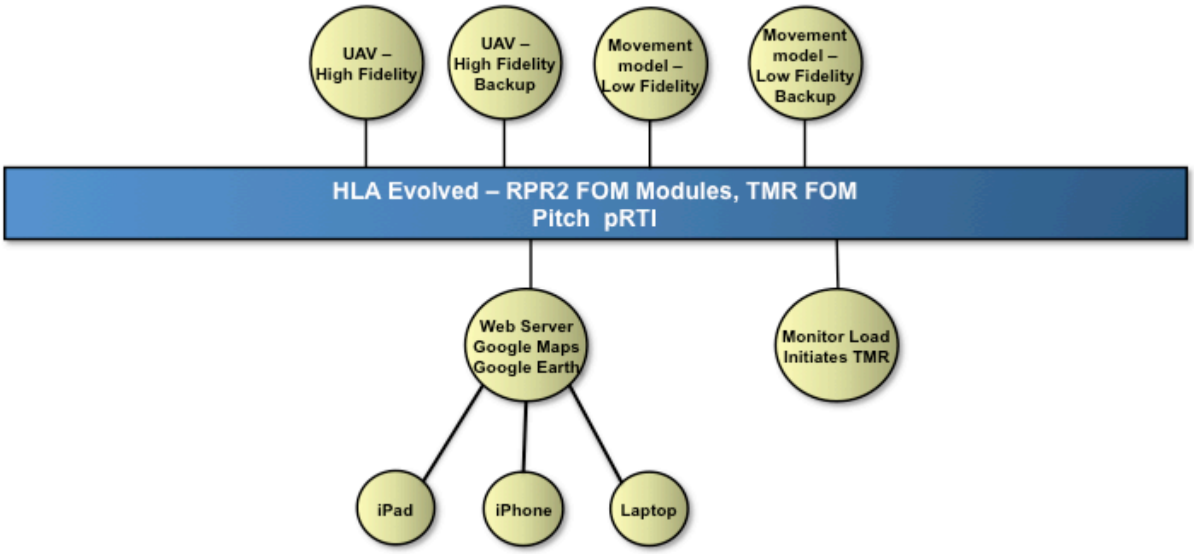

Figure 6: BAE Systems C2 Demo – before fail-over

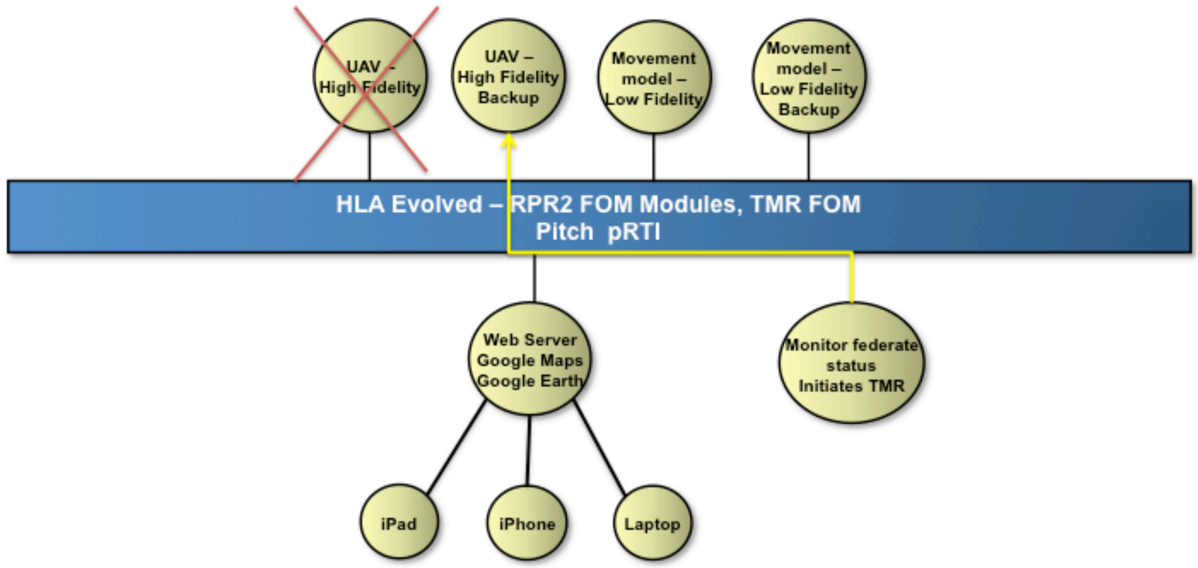

Figure 6: BAE Systems C2 Demo – after fail-over

5.2 Federation

The federation uses the RPR2 FOM for representing platforms as well as a pattern for Transfer of Modeling Responsibility (TMR) that will be discussed further in NATO MSG 106. Each federate provides data to the federation about its capabilities for simulating different types of platforms as well as the fidelity level of the simulation. The CPU and memory load of the federates is also provided to the federation. This makes it possible to handle fail-over situations where it is necessary to find a new simulator that can model the behavior of platforms from federates that have been lost. All federates in the federation are rated based on their simulation capability, simulation fidelity and their CPU and memory load and the federate with the best score is selected as the new owner. The process of finding a new owner is automatic by default but it is possible for an operator to manually select a new owner of an entity from a Google Maps Web interface.

When the lost federate joins the federation again the monitoring federate initiates the Transfer of Modeling Responsibility to return ownership to the original owner.

The federation consists of the following federates:

- A mapping and controller federate. It shows platform positions. It also enables the operator to request that another federate takes over the responsibility for a platform.
- A number of simulators that can model platforms according to the RPR2 FOM, for example UAV simulators.
- A load balancing and fault tolerance management federate.

5.3 HLA Evolved aspects and experiences

This federation uses modular FOMs. It also uses the fault tolerance semantics of HLA Evolved. Lost federates are detected using both the HLA Evolved “Federate Lost” interaction and by monitoring the disappearance of object instances.

The federation implements the following fault tolerance design patterns, described in a previous paper (05S-SIW-048).

- The reoccurring federate, meaning that the federate that has lost connection to a federation will periodically try to reconnect.
- The fail-over federate, meaning that there is a backup federate standing by to take over ownership of an instance.
- The fault-monitoring federate, that subscribes to MOM information and monitors and assesses the state of the federation, in particular with respect to participating federates.

This federation also uses the HLA Evolved Smart Update Rate Reduction (SURR) to reduce the update rate for platform position updates to federates with limited bandwidth or processing power.

6. Some Other Noteworthy HLA Evolved Work

6.1 German NAVY FOM

The new German Maritime Federation Object Model [19] aims to prove interoperable simulation capabilities for the German naval command and control systems. Important federations to interoperate with include the US Navy NCTE, the

US Joint JLVC, NATO federations and the German Forces distributed network SuTBw. The work has been initiated, guided and performed by several organizations including the German Modeling and Simulation Commissary, The Combat Direction Systems Activity (CDSA), the NavCCSysCom and the Novonics Corporation.

The object model uses HLA Evolved FOM modules. It is based on the RPR FOM [16] version 2d17 and the project considers aligning with future, standardized version of the RPR FOM. Additional FOM modules cover areas like Link 16 communications, emitters and transponders, sonobuoys, acoustics and more.

6.2 Object Oriented Middleware Generator using the Web Services API

Pitch Developer Studio [14] generates HLA middleware in C++ or Java for a particular FOM or a set of FOM modules. This middleware can then be integrated into a simulation that requires HLA capabilities. The middleware then provides C++ or Java objects for all instances in the federation, including type-safe "setters" and "getters" for attributes and parameters.

The generated code is compatible with the HLA Evolved, 1516-2000 and HLA 1.3 APIs from most leading RTIs using either the C++ or Java APIs, without recompilation. A new feature is that a federate developed using Pitch Developer Studio also supports the Web Services API of an RTI. This means that a federate can participate using the C++ API one day and in another federation using the Web Services API the next day.

6.3 Data logging in Pitch Recorder

Pitch Recorder [20] is a data logger that supports HLA Evolved, HLA 1516-2000 and HLA 1.3, as well as DIS, Voice and user-defined formats. All formats can be recorded in parallel and in sync. When recording data from an HLA Evolved federation it can use the new HLA Evolved data logging features. It is possible to specify that a particular Pitch Recorder channel shall only record data (object registrations, attribute update, interactions) from a particular named federate. FOM modules are also supported.

6.4 FOM Development in Pitch Visual OMT

Pitch Visual OMT [21] is a FOM and SOM development tool that has been used in most of the above projects. It has several ways to check the correctness of an HLA Evolved FOM or a set of FOM modules. It can use the HLA Evolved Schemas to check a FOM for example to verify that it contains all necessary data to initialize a federation execution. In addition to this it provides a built-in rule engine that checks a set of FOM modules for problems on three levels:

- Error, meaning that there is a problem in this set of FOM modules. They do not contain enough information to initialize a federation execution.
- Warning, meaning that there is a minor problem that needs to be corrected, for example a missing definition of a data type.
- Information, meaning that it doesn't follow best practice, for example by not documenting the semantics of an attribute or not providing a point of contact.

7. Feature Usage Summary and Discussion

This section attempts to summarize the usage of HLA Evolved and the new features in particular.

First of all it is important to notice that almost all of the new HLA Evolved features have been successfully used in practice, even though the standard was published in August 2010, which is a year and a half ago. It is also worth noting that HLA Evolved has already been used in such a large and demanding federation as Viking 11, which indicates the maturity of both the standard and some RTI implementations.

Modular FOMs have been use in more or less all federations. They improve the development and maintenance of almost any federation, large or small. The need for modification of existing federates is very limited.

Fault Tolerance support is a highly requested feature for many federations that have grown in size or that needs to be deployed under less than perfect conditions. This requires a redesign of the federation agreement and in some cases major modifications of the federates that may need to run in both connected and disconnected mode and to support late joiners. Nevertheless one federation has successfully used it.

The Evolved Dynamic Link Compatibility (EDLC) features of HLA Evolved have been tested in the Smackdown federation. This federation is quite small but it uses a wide range of HLA Services, including Time Management. This makes it a good test. EDLC is important to build a good marketplace where federation can easily switch between RTIs and GOTS or COTS federate can be expected to work with any compliant RTI.

The Smart Update Rate Reduction (SURR) has been used in one federation but could have been useful in some of the other federations to reduce the load on selected federates.

Standardized time types are important for the reuse of time managed federates. This list contains only one time-managed federation, Smackdown, which does indeed use such a representation. Note that the tools Pitch Recorder and Pitch Developer studio also supports this. It is very hard to develop COTS tools that support non-standard time representation since a tool needs not only to receive the unknown data but also to interpret and process it.

Improved support for data logging has only been used in one of the examples, namely the data logger. Still any federation can use this HLA Evolved feature without modification since it only requires the acquisition of a data logger with such support.

8. Conclusions

A number of federations have been already been developed using HLA Evolved. The have used almost all of the major new features. All new HLA Evolved features have worked as expected.

Large exercises with thousands of participants have been successfully performed using HLA Evolved infrastructures, which proves the maturity of several implementations.

The most important conclusion is that the new features of the HLA Evolved standard match a number of actual requirements of simulation and federation users.

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